Diffusion-weighted MRI for body imaging applications

Bachir Taouli, M.D.

Assistant Professor, Department of Radiology

New York University Medical Center

Diffusion is the thermally induced motion of water molecules in biological tissues, called Brownian motion. Diffusion-weighted MRI (DWI) - by means of apparent diffusion coefficient (ADC) calculation - can be used for in vivo quantification of the combined effects of capillary perfusion and diffusion. With the advent of echoplanar imaging (EPI), DWI of the abdomen has become possible with fast imaging times minimizing the effect of gross physiologic motion from respiration and cardiac movement. Several studies have investigated the use of DWI for liver(1-4), kidney (5-8), prostate (9) and breast imaging (10).

In this presentation, we will review our experience with DWI for body imaging applications. The lecture will include:

1. MR technique of DWI for body applications
2. DWI for liver imaging applications
3. DWI for renal imaging applications
4. Other applications
5. Future improvements in DWI for body imaging

1. MR technique of DWI for body applications:

We use breath-hold single shot spin echo planar imaging (SSEPI) sequences to obtain diffusion-weighted images on 1.5 T scanners with phased-array coils. A pulse trigger to the diastolic heart phase to reduce motion artifacts can be used (11). A short TR (around 1300 msec) is used to decrease acquisition time, and a minimum TE (around 60-70 msec, as close as possible to the liver T2), 3 to 4 acquisitions, and a 128x192 matrix. We use parallel imaging (SENSE or GRAPPA, with a parallel imaging factor of 2) to decrease distortion and ghosting artifacts (12) and also to obtain a shorter TE and better signal to noise ratio in the liver (13). We typically use b-values between 400-800 sec/mm^2. If low b-values (< 100 sec/mm^2) are used, ADC maps can be contaminated by perfusion. However, the drawback of high b-values is signal loss, with noise contamination in the ADC measurement.

We have recently implemented a respiratory-triggered SSEPI sequence in the abdomen using a navigator echo technique, which -in our preliminary results- seems to provide better image quality and a more reliable ADC calculation, when compared to the breath-hold version.

2. DWI for liver imaging:

2. 1 Liver lesion characterization:

DWI has been mostly used for liver lesion characterization (1-4). Most studies have found higher ADC values in benign lesions, as compared to malignant lesions, with some degree of overlap. Liver cysts have the highest values, followed by hemangiomas, the lowest values are found in HCC and metastases.
We demonstrated in a prior study that a threshold ADC value <1.5 x 10^{-3} mm^2/sec for the diagnosis of malignant liver lesions would result in a sensitivity and specificity of 84% and 89% (using b-values of 0-500 sec/mm^2) (4).

2.2 Liver lesion detection:

By using a small b-value < 100 sec/mm^2, T2-weighted images with vessel suppression (black-blood images) can be achieved in the liver, and better lesion conspicuity could be obtained. Hussein et al have shown that an optimized SSEPI sequence had comparable image quality and SNR when compared to a standard respiratory-triggered T2-weighted TSE sequence (14)
Our preliminary experience showed a better sensitivity for liver lesion detection using DWI with a b-value of 50 sec/mm^2 when compared to the T2-weighted sequence (sensitivity of detection of lesions > 1 cm was 84.7% for DWI vs. 71.7% for T2).

2.3 Diagnosis of liver fibrosis:

Several studies have shown that decreased ADCs in liver cirrhosis versus non-cirrhotic liver (1-4,15), which may be related to restricted water diffusion in relation with fibrosis.
In our preliminary experience, like others have showed (16), we demonstrated that DWI can be used to quantify different degrees of liver fibrosis in patients with chronic hepatitis (17). High b-value > 300 sec/mm^2 is needed to show the differences between different degrees of liver fibrosis.

3. DWI for renal imaging:

3.1 DWI for diffuse renal disease:

Several studies have explored DWI in normal kidney and diffuse renal disease (5-8). Namimoto et al (7) showed decreased ADC values in patients with chronic renal failure, when compared with patients with normal renal function.

3.2 DWI for focal renal mass characterization:

A recent study by Cova et al showed restricted diffusion in malignant renal lesions, as opposed to benign lesions (18). Our experience is similar (19). We showed also a significant decrease of ADC values of cystic renal lesions with increasing degrees of complexity according to the Bosniak classification.

4. Other applications:

DWI has been used to diagnose prostate cancer which shows restricted diffusion when compared to non-cancerous prostatic tissue (9,20)

5. Future improvements in DWI:

Image quality of DWI is still limited, related to low resolution and limited SNR. A non-breath hold DWI sequence using navigator echo correction improves the image quality and lesion to liver contrast. In addition, signal gain with 3T will likely also improve image quality. Several applications in body imaging are also under way, such as whole body diffusion imaging in oncologic patients.

References:

1. Namimoto T, Yamashita Y, Sumi S, Tang Y,Takahashi M. Focal liver masses: characterization with diffusion-weighted echo-planar MR imaging. Radiology 1997;204:739-744.
2. Kim T, Murakami T, Takahashi S, Hori M, Tsuda K,Nakamura H. Diffusion-weighted single-shot echoplanar MR imaging for liver disease. AJR Am J Roentgenol 1999;173:393-398.
3. Ichikawa T, Haradome H, Hachiya J, Nitatori T,Araki T. Diffusion-weighted MR imaging with single-shot echo-planar imaging in the upper abdomen: preliminary clinical experience in 61 patients. Abdom Imaging 1999;24:456-461.
4. Taouli B, Vilgrain V, Dumont E, Daire JL, Fan B,Menu Y. Evaluation of liver diffusion isotropy and characterization of focal hepatic lesions with two single-shot echo-planar MR imaging sequences: prospective study in 66 patients. Radiology 2003;226:71-78.
5. Ries M, Jones RA, Basseau F, Moonen CT,Grenier N. Diffusion tensor MRI of the human kidney. J Magn Reson Imaging 2001;14:42-49.
6. Chan JH, Tsui EY, Luk SH, et al. MR diffusion-weighted imaging of kidney: differentiation between hydronephrosis and pyonephrosis. Clin Imaging 2001;25:110-113.

7. Namimoto T, Yamashita Y, Mitsuzaki K, Nakayama Y, Tang Y,Takahashi M. Measurement of the apparent diffusion coefficient in diffuse renal disease by diffusion-weighted echo-planar MR imaging. J Magn Reson Imaging 1999;9:832-837.
8. Fukuda Y, Ohashi I, Hanafusa K, et al. Anisotropic diffusion in kidney: apparent diffusion coefficient measurements for clinical use. J Magn Reson Imaging 2000;11:156-160.
9. Hosseinzadeh K,Schwarz SD. Endorectal diffusion-weighted imaging in prostate cancer to differentiate malignant and benign peripheral zone tissue. J Magn Reson Imaging 2004;20:654-661.
10. Guo Y, Cai YQ, Cai ZL, et al. Differentiation of clinically benign and malignant breast lesions using diffusion-weighted imaging. J Magn Reson Imaging 2002;16:172-178.
11. Murtz P, Flacke S, Traber F, van den Brink JS, Gieseke J,Schild HH. Abdomen: diffusion-weighted MR imaging with pulse-triggered single-shot sequences. Radiology 2002;224:258-264.
12. Bammer R, Auer M, Keeling SL, et al. Diffusion tensor imaging using single-shot SENSE-EPI. Magn Reson Med 2002;48:128-136.
13. Taouli B, Martin AJ, Qayyum A, et al. Parallel imaging and diffusion tensor imaging for diffusion-weighted MRI of the liver: preliminary experience in healthy volunteers. AJR Am J Roentgenol 2004;183:677-680.
14. Hussain SM, De Becker J, Hop WC, Dwarkasing S,Wielopolski PA. Can a single-shot black-blood T2-weighted spin-echo echo-planar imaging sequence with sensitivity encoding replace the respiratory-triggered turbo spin-echo sequence for the liver? An optimization and feasibility study. J Magn Reson Imaging 2005;21:219-229.
15. Amano Y, Kumazaki T,Ishihara M. Single-shot diffusion-weighted echo-planar imaging of normal and cirrhotic livers using a phased-array multicoil. Acta Radiol 1998;39:440-442.
16. Koinuma M, Ohashi I, Hanafusa K,Shibuya H. Apparent diffusion coefficient measurements with diffusion-weighted magnetic resonance imaging for evaluation of hepatic fibrosis. J Magn Reson Imaging 2005;22:80-85.
17. Tolia A, Losada M, Chan E, Lee VS, Yee H,Taouli B. Quantification of liver fibrosis using diffusion-weighted imaging in patients with chronic hepatitis: preliminary experience. RSNA 2005.
18. Cova M, Squillaci E, Stacul F, et al. Diffusion-weighted MRI in the evaluation of renal lesions: preliminary results. Br J Radiol 2004;77:851-857.
19. Thakur R, Israel G, Lee VS, Hecht EM,Taouli B. Diffusion-weighted MR imaging for characterization of renal masses: preliminary results. ISMRM proceedings 2005.
20. Issa B. In vivo measurement of the apparent diffusion coefficient in normal and malignant prostatic tissues using echo-planar imaging. J Magn Reson Imaging 2002;16:196-200.